NISTIR 6030

THIRTEENTH MEETING OF THE UJNR PANEL ON FIRE RESEARCH AND SAFETY, MARCH 13-20, 1996

VOLUME 1

Kellie Ann Beall, Editor

June 1997
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

U.S. Department of Commerce
William M. Daley, *Secretary*
Technology Administration
Gary R. Bachula, *Acting Under Secretary for Technology*
National Institute of Standards and Technology
Robert E. Hebner, *Acting Director*

Cost-Effective Compliance with the Life Safety Code for Health Care Occupancies

Stephen F. Weber
Barbara C. Lippiatt
Office of Applied Economics
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg MD 20899

ABSTRACT

ALARM, *A*lternative *L*ife Safety *A*nalysis for *R*etrofit Cost *M*inimization, is a personal computer software tool that helps building managers and fire safety officers achieve cost-effective compliance with the widely-used *Life Safety Code*. This first version of *ALARM* supports analysis of health care occupancies. An equivalency provision of the code, called the Fire Safety Evaluation System, establishes a scoring system that permits trade-offs among safety features. *ALARM* exploits this flexible provision by helping users find cost-effective solutions to compliance. *ALARM* generates a set of near least cost alternative code compliance strategies and their estimated costs. These strategies offer decision support by providing a set of alternatives from which to select the most appropriate code compliance strategy based on both cost and design considerations. The software offers a code compliance optimizer, a comprehensive file manager, and a full-screen data editor. The optimization method used in *ALARM* has been field tested in nearly 100 hospitals since 1981. Cost savings have averaged between 30 and 35 percent of the cost of prescriptive compliance strategies. Future versions of *ALARM* could address other building occupancies.

1. Introduction

This paper describes new software designed to help fire safety officers and building managers at health care facilities achieve cost-effective compliance with fire codes. The software is called ALARM, which stands for *A*lternative *L*ife Safety *A*nalysis for *R*etrofit Cost *M*inimization, and was developed at the National Institute of Standards and Technology's Building and Fire Research

Laboratory in cooperation with the U.S. Public Health Service (USPHS).[1] The software generates a set of alternative compliance strategies, and their estimated costs, for meeting the *Life Safety Code (LSC)*[2] of the National Fire Protection Association (NFPA). The LSC is a widely used, voluntary code for identifying the minimum level of fire safety in buildings. Compliance with the LSC is a condition for accreditation by the Joint Commission on Accreditation of Health Care Organizations.

The primary code of the LSC is prescriptive, since it requires specific solutions for fire safety. For example, it might require a minimum flame spread rating for interior finishes and the presence of manual fire alarms. However, a special provision allows for **alternative code compliance** through a goal-oriented, equivalency approach. This approach permits **combinations** of fire safety parameters to achieve a level of fire safety equivalent to that required by the prescriptive code.

2.0 Background

Health care is the first building occupancy to be covered by a formal equivalency system. The system was originally developed in the late 1970's at NIST (then the National Bureau of Standards).[3] The NFPA subsequently adopted this equivalency system into the Life Safety Code in 1981.[4] This equivalency method, known as the Fire Safety Evaluation System (FSES), has been modified and updated several times since then. The current (1995) version is published as NFPA 101A and includes FSESs for business, board and care, and correctional occupancies.[5] *ALARM* currently supports only the FSES for health care occupancies.

The health care occupancy FSES of NFPA 101A requires analysis and scoring of each zone in the facility. A zone is building space that is separated from all other spaces by floors, horizontal exits, or smoke barriers. The analysis looks at 13 fire safety parameters with up to seven levels of safety for each parameter, for a total of 56 safety levels. Zones earn points for each safety parameter

---

[1]Stephen F. Weber and Barbara C. Lippiatt, *ALARM 1.0: Decision Support Software for Cost-Effective Compliance with Fire Safety Codes*, National Institute of Standards and Technology, NISTIR 5554, Gaithersburg MD 20899, December 1994. The software and manual are available for $9.95 from NFPA, One-Stop Data Shop, 1 Batterymarch Park, P.O. Box 9101 Quincy, MA 02269-9101 (Phone: 617-984-7450).

[2]National Fire Protection Association, NFPA 101, *Life Safety Code*, 1994 edition, Quincy, MA, 1994.

[3]H. E. Nelson and A. J. Shibe, *A System for Fire Safety Evaluation of Health Care Facilities*, National Bureau of Standards, NBSIR 78-1555, Washington, DC, 1980.

[4]National Fire Protection Association, *Code for Safety to Life from Fire in Buildings and Structures*, NFPA 101-1981, Appendix C, Quincy, MA, 1981.

[5]National Fire Protection Association, "Fire Safety Evaluation System for Health Care Occupancies," Chapter 3 of NFPA 101A, *Guide on Alternative Approaches to Life Safety*, 1995 edition, Quincy, MA, 1995.

based on its impact on each of four categories of fire safety. Point totals earned across the 13 parameters in a zone are then compared with the mandatory point requirements for the four fire safety categories: (1) containment, (2) extinguishment, (3) people movement, and (4) general safety. If the point totals meet or exceed all four requirements, the zone achieves equivalency. Every zone must make the grade for the building as a whole to be in conformance.

3.0 Cost Minimization Method

Since the mandatory point requirements are established only for total scores across all fire safety parameters, tradeoffs among the 13 fire safety parameters are possible. For example, in exchange for more widespread automatic sprinklering, less smoke control may be permitted. These potential tradeoffs generate the opportunity for savings in complying with fire codes. Less expensive fire safety parameters may be substituted for more expensive ones, all the while maintaining an acceptable level of fire safety. With four independent mandatory point requirements, 13 fire safety parameters each with up to seven levels of fire safety, and many zones to analyze, the problem quickly becomes unwieldy and difficult to solve by manual computation and comparison. A cost minimization method, implemented in a software tool, is needed.

A cost minimization method for this kind of problem was originally developed by Chapman and Hall and applied to the 1981 edition of the FSES for health care occupancies through the software, *F*ire *S*afety *E*valuation *S*ystem *C*ost *M*inimizer (*FSESCM*).[6] The method is an application of the mathematical technique known as linear programming. This approach efficiently evaluates all possible code compliance solutions. The general idea is to balance improvements in fire safety scores with the costs necessary to achieve them. In this way, the least-cost means of achieving code compliance can be identified.

Since the 1981 edition of the FSES for health care occupancies was adopted, the *FSESCM* software has been extensively field tested. Important changes have occurred in fire safety technology for buildings, in construction costs, and in the FSES itself. Moreover, the improved performance of computer hardware and software development tools now support user-friendly, interactive software. In response, the optimization software, the cost estimating algorithms, and the supporting data have all been updated. In addition, an interactive environment for the updated optimization software has been developed and integrated into *ALARM*. All of the cost algorithms and supporting data are thoroughly documented.

---

[6]For an extended discussion of FSESCM and the underlying optimization method, see R. E. Chapman and W. G. Hall, *User's Manual for the Fire Safety Evaluation System Cost Minimizer Computer Program*, National Bureau of Standards, NBSIR 83-2797, Washington, DC, 1983; R. E. Chapman and W. G. Hall, *Programmer's Manual for the Fire Safety Evaluation System Cost Minimizer Computer Program*, National Bureau of Standards, NBSIR 83-2749, Washington, DC, 1983; and R. E. Chapman, "Assessing the Costs of Fire Protection in Health Care Facilities," *Fire Safety Journal*, Vol. 9, No. 2, 1985, pp. 221-231.

4.0 Data Requirements

ALARM allows easy, quick, and reliable data entry through an integrated file manager and full-screen data editor. The file manager lists all building data files in the current directory. These are files created with the data editor and containing all data necessary for running the optimizer for an entire building. The software even includes a sample building file. The file manager is the command center from which the user can perform typical data file operations, such as copying, renaming, deleting, and printing, as well as the primary operations of entering building and zone data and running the optimizer.

The data editor is used to enter data on the hospital building under study. The editor displays on-screen prompts and complete data validation routines to facilitate the creating and editing of error-free data files. To facilitate the data entry process, the manual offers a data collection form that mirrors the layout of the data editor.

Data must be entered on the building as a whole, on each zone, and on each fire safety parameter within each zone. Building information consists of general information, a building qualifier, construction cost modifiers, and a zone listing. General information includes the name and address of the building. The building qualifier indicates whether the building has sprinklers and whether it is new, in order to determine in part the four mandatory point requirements. The construction cost modifiers are used to adjust by the same percentage the automatic cost estimates for all retrofits. These modifiers permit time- and location- specific cost adjustments to all default unit costs.

Data needed for each zone include its name, identification number, floor number, and occupancy risk factors. The risk factors are used to determine the mandatory point score for general safety. They cover patient mobility, patient density, zone location, ratio of patients to attendants, and average patient age.

For each of the 13 fire safety parameters, users must enter the current fire safety state of the zone and all the retrofit quantities needed to achieve each state that is safer than the current state. For some fire safety parameters special design specifications may be entered to further define a zone's fire safety status or potential retrofits. For example, a specification for the Automatic Sprinklers parameter covers whether asbestos must be removed as part of the sprinkler installation. Users may rule out any state to force the optimization procedure to ignore it. The cost estimation algorithms use the retrofit quantities and special design specifications to compute the cost of moving from the current state to each of the safer states available. A cost adjustment (positive or negative) may also be entered for each state to include costs for a retrofit not on the retrofit list or to reduce the automatic cost estimate.

5.0 Reports

Once the data on all the zones has been entered and saved in the file, the user selects the optimizer feature from the file manager. The optimizer generates a report file with alternative code compliance options and their estimated costs. Users can select the most appropriate compliance option based on both cost and design considerations. For benchmarking purposes, the optimizer also reports the prescriptive solution cost for each zone and for the building as a whole.

The report file consists of key FSES tables, zone reports, and building summary reports, as shown in exhibit 1. The FSES tables are included for informational purposes. There are three zone reports. The first report gives occupancy risk factors and the current fire safety state, the prescriptive compliance state, and the retrofit quantities entered for each fire safety feature. The second zone report shows the total retrofit costs for each fire safety state and the prescriptive compliance cost for the zone as a whole. The third report lists all code compliance strategies generated by the optimizer for the zone. Each strategy is identified by its solution states for the 13 fire safety parameters. The total compliance cost for each strategy is also reported. Finally, this report gives the number of surplus points earned by each strategy in excess of the four mandatory point requirements.

Exhibit 1. Optimization Reports

1. FSES Tables
    - 1.1 Occupancy Risk Factors
    - 1.2 Mandatory Safety Requirements
    - 1.3 Fire Safety Parameter Values

2. Zone Reports
    - 2.1 Data Inputs
    - 2.2 Estimated Retrofit Costs
    - 2.3 Code Compliance Strategies

3. Building Summary Reports
    - 3.1 Design Class Reports (20)
    - 3.2 Prescriptive Solution Report

The Building Summary Reports match common compliance strategies across all zones in the building. Twenty default design classes are built into the software. A design class defines specific safety levels for some of the fire safety parameters. For example, one default design class calls for automatic sprinklers throughout the entire building, a single deficiency in hazardous areas, no horizontal exits, and no changes in construction type, zone dimensions, or smoke detection. The Design Class Reports identify the least-cost compliance strategy that satisfies the design class specifications. The reports are sorted in order of total compliance costs. If a zone cannot achieve code compliance under a given design class, that class is not reported. Each report provides a set of alternatives from which to select the most appropriate compliance strategy based on both cost and design considerations. If the default design classes do not satisfy design requirements for a facility, the user may select a customized set of solutions from the individual Zone Reports. The Prescriptive Solution Report gives the cost of prescriptive compliance for the total building.

6.0 Conclusions and Future Directions

Since 1981, the approach used in *ALARM* has been field tested by the USPHS in a large number of military, public, and private hospitals. The cost savings have been substantial; *ALARM*'s economical, equivalency solutions are typically saving hospitals between 30 and 35 percent of the cost of implementing prescriptive codes. Over 250 copies of *ALARM* have been sold to date. In 1993, the software was applied to the largest hospital yet, the 60-zone, 62,710 square meter (675,000 square foot) Wright-Patterson Air Force Base hospital in Ohio. *ALARM* estimated that the cost savings from using the alternative FSES solution was over $500,000. In the same year the forty-bed hospital at Yokota Air Force Base in Fussa, Japan was also surveyed, resulting in an estimated cost savings of $136,000 compared with the prescriptive code approach. The results of the surveys on 86 military hospital facilities representing about 16,000 beds show estimated cost savings of over $35 million, an average savings of $2,200 per bed.

This first version of *ALARM* is designed with built-in flexibility for efficiently making changes for future versions of the software. The software will need to be revised when the FSES for health care occupancies is significantly modified or when retrofit cost estimates become so outdated that across-the-board inflation adjustments are no longer realistic. A network version would permit many users to edit the same building data file simultaneously. On-site data entry could be enabled through a laptop and ultimately a pen-based version of the software. On-site data entry would improve productivity because building data is currently developed in two stages: notes are made on building blueprints on site, then they are later translated into data for entry into *ALARM*. A pen-based computing application could load digitized blueprints into a hand-held computer. Notes made on these digitized blueprints could automatically be converted into the necessary building data.

With the success of the FSES for health care occupancies, equivalency systems were developed for business, board and care, and detention and correctional occupancies. The *ALARM* methodology for reducing code compliance costs is equally applicable to these and even other occupancies as more FSES systems are developed. Software tools tailored to these occupancies could be developed in the future.

Discussion

Brian Meacham: I think that's probably a wonderful tool for doing cost benefit analyses for prescriptive code options. NFPA 101A is not a performance-based code, and it doesn't say that it is anywhere in the document to my knowledge. The options that you're giving on the output of 101A are the same prescriptive requirements that are in NFPA documents that are just lessening of some requirements over another one. There is no measurement of performance of how the building operates. I think there is a fundamental difference between looking at the performance of the building in its entirety against the effects of fire verses the cost benefit of one system over another. And so I see a good benefit for this tool in reducing costs in the current system. I hope that it will be applicable to performance codes when we have them in the future.

Barbara Lippiatt: I think 101A is the first step towards what Brian refers to as a true performance-based code and that a tool such as ALARM can be used to make the trade-offs necessary, whether it's applied on a more restrictive basis like 101A, or a true trade-off basis such as would be provided by a true performance-based code.

James Quintiere: I have two questions. First, do you know if there's been any retrospective analysis on the equivalency criteria used in this evaluation system since it was developed in the 70s? And maybe there is different thinking now with some new knowledge.

Barbara Lippiatt: Well, the code has been updated a number of times. But, Dick Bukowski tells me that, no, there has not been any retrospective analysis done.

James Quintiere: Just another question out of curiosity. Since we are talking about performance codes and if we were to apply that to fire, do you know of any examples where performance codes have been used in other safety areas? When they reach the appropriate level of safety, do they cost more? See, I don't know if it's clear that it will cost more or less if we go to performance-based codes.

Barbara Lippiatt: Unfortunately, I usually use the fire example in my other work to illustrate the performance concept. So the answer is: not to my knowledge on the first part of your question. And the second part, I believe that the ALARM software points in the direction that there can be cost savings in the performance-based approach.

Takeyoshi Tanaka: Construction costs vary every year, depending on what materials you use and what equipment you use. And there is also some regional variance. So how often do you update data? And do you take into consideration yearly changes of construction costs in you system? That's the first question. And the second question: you said that this system was used in Japan. How did you obtain cost-related data?

Barbara Lippiatt: The system is now based on 1991U.S. average costs. We used a cost adjustment for Japan of a factor between 3 or 4 times those costs. We provide cost adjustments to take account of the regional and time-sensitive cost differences, and we hope to have further funding to update the costs in the future.

Discussion cont.

John Hall: I have three brief comments related to previous questioners. First, I think prescriptive and performance-based codes are better thought of not as strict alternatives, but as two ends of a spectrum. Our current codes are not purely prescriptive, but they are more prescriptive than NFPA 101A, and so I think you characterization of ALARM is correct. My second point is that in answer to Dr. Quintiere, if you would do performance based codes, as most people do, as either an alternative or a framework in which the prescriptive codes are an accepted solution, it is impossible for performance-based codes to cost more because if they do, you don't use them. And finally, because your analysis compares low cost solutions to the prescriptive solution, it is not as dependent on up to date cost data, it is looking at relative comparisons and they are not as likely to change over time or between regions.

Yuji Hasemi: I was involved in the safety evaluation of a hospital building construction in Japan, and I found that a lot of times we ran into the situation where safety and convenience or use of the building equipment just did not go along with each other. For example, fire safety can be satisfied by building a wall, however, it is very inconvenient to have a wall in a practical sense. I assume that you also run into problems of this kind, particularly, when you consider retrofitting effects in existing buildings. Do you take this kind of thing into consideration?

Barbara Lippiatt: That's where the engineering judgement comes in. The engineer that surveys the building has the option of selecting from the identified list of retrofitting effects or entering any other retrofitting effect that he or she deems appropriate.

END: March 13, 1996